6th International Symposium for Farming Systems Design

Integrating isolated trees improves the agricultural performance assessment of smallholder farming systems at landscape scale in the Senegalese peanut basin

Leroux L., Gbodjo J-E., Djiba S., Tounkara A., Ndao B., Diouf AA., Soti V., Affholder F., Tall L., Balde A., Clermont-Dauphin C.

louise.leroux@cirad.fr
https://louise.leroux.igeo.fr/

« Make our planet treed again »

(Montpellier Declaration, World Agroforestry Congress, 2019)

© LEROUX L. CIRAD. 2018

© DATA//WAX. 2019

« Make our planet treed again »

(Montpellier Declaration, World Agroforestry Congress, 2019)

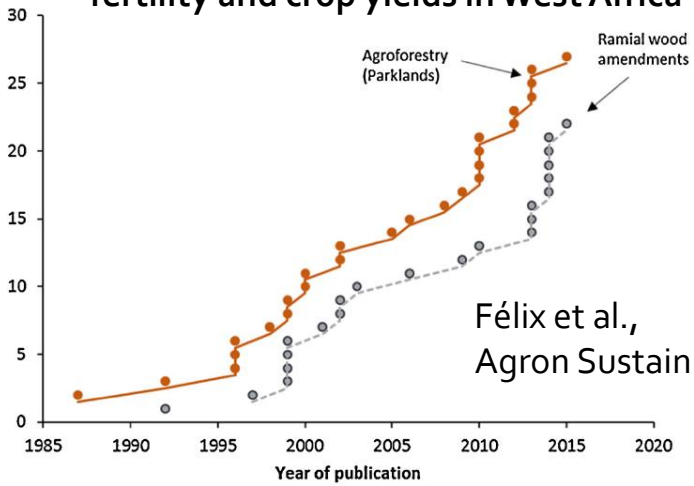
Agroforestry parklands in face of SDG's

SUSTAINABILITY **EQUITY** **RESILIENCE**

Background & objectives

An increasing scientific interest in understanding effects of parklands on soil and crop productivity ….

Cumulative number of publications : trees vs soil fertility and crop yields in West Africa

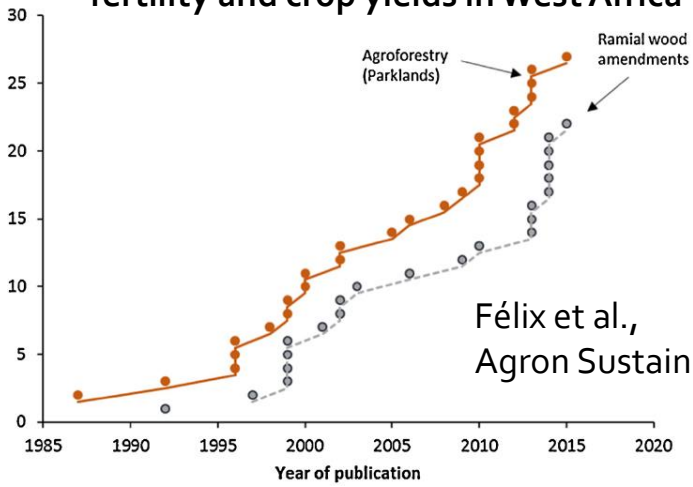


Félix et al.,
Agron Sustain Dev, 2018

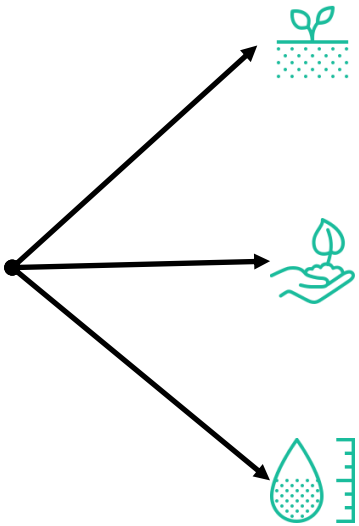
Background & objectives

An increasing scientific interest in understanding effects of parklands on soil and crop productivity ….

Cumulative number of publications : trees vs soil fertility and crop yields in West Africa



Félix et al.,
Agron Sustain Dev, 2018



SUPPORTING SERVICES

Ex. Increasing of SOC

PROVISIONING SERVICES

Ex. Increasing of cereal yields under *F.albida*

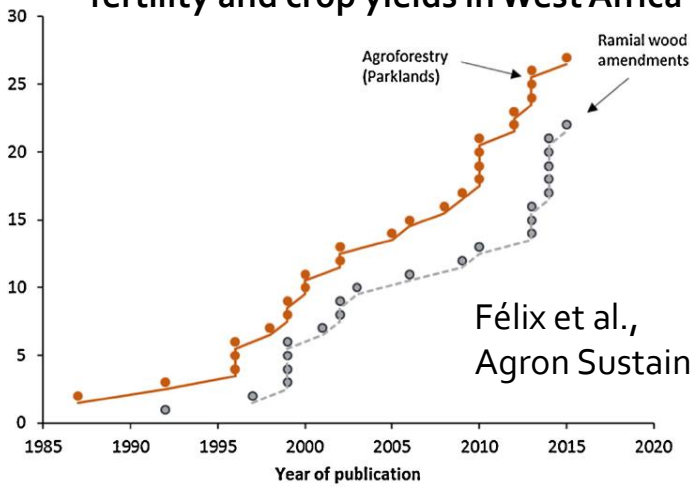
REGULATING SERVICES

Ex. Microclimate modification

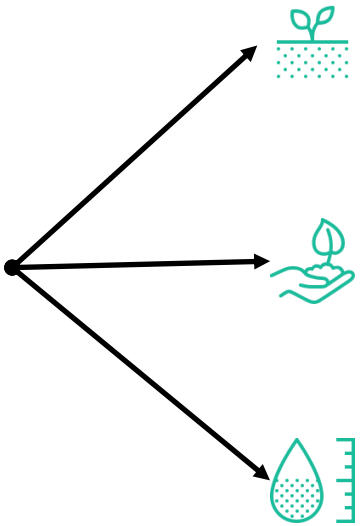
Background & objectives

An increasing scientific interest in understanding effects of parklands on soil and crop productivity ….

Cumulative number of publications : trees vs soil fertility and crop yields in West Africa



Félix et al.,
Agron Sustain Dev, 2018



SUPPORTING SERVICES

Ex. Increasing of SOC

PROVISIONING SERVICES

Ex. Increasing of cereal yields under *F.albida*

REGULATING SERVICES

Ex. Microclimate modification

… But still some challenges

1 – Most of studies are conducted **at tree scale**

2 – Limited knowledge on the impacts of **parklands pattern** (composition / structuring) on agricultural performance of farming system **at landscape scale**

3 – **Models** (crop process-based or statistical) accounting for trees in agricultural landscape remain scarce

Background & objectives

Background & objectives

At landscape scale :

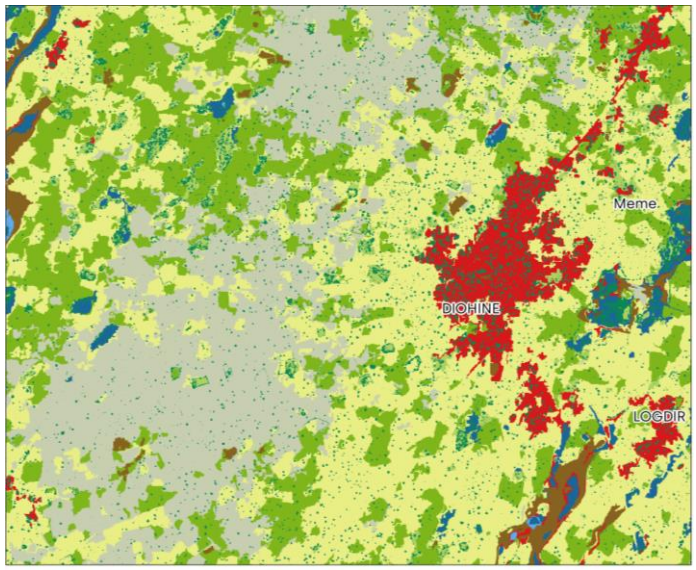
1 - To evidence the contribution of parklands structuring on the agricultural performance of smallhoder farming systems

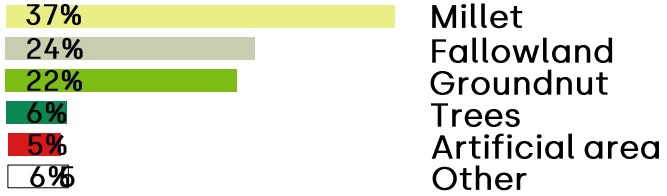
2 – To estimate crop yields and it's spatial heterogeneity

Where, What, How? Materials & Methods

The « old » peanut basin : the Senegalese breadbasket

A agricultural landscape dominated by rainfed crops …





Ndao et al., 2019

CLIMATE

*Sudanian climate
*Annual rainfall : **500-650 mm**
*Rainy season : July to Oct.

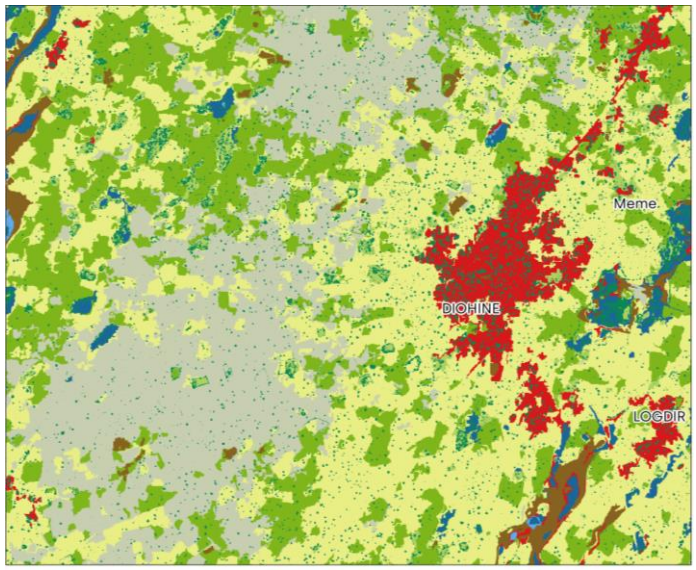
FARMING SYSTEM

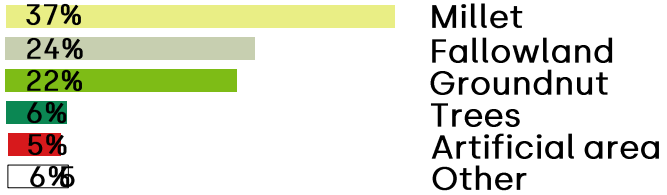
* Agriculture dominated by:
-**Millet** (on-farm consumption)
-**Groundnut** (cash crop)
-Livestock
* **Low input**

Where, What, How? Materials & Methods

The « old » peanut basin : the Senegalese breadbasket

A agricultural landscape dominated by rainfed crops …





Ndao et al., 2019

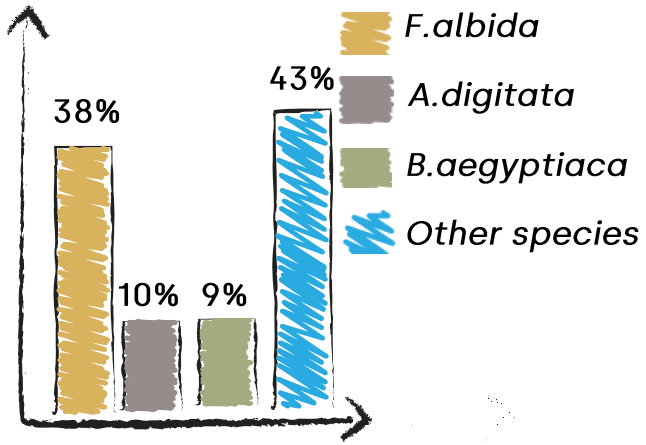
Climate

*Sudanian climate
*Annual rainfall : **500-650 mm**
*Rainy season : July to Oct.

Farming system

* Agriculture dominated by:
-**Millet** (on-farm consumption)
-**Groundnut** (cash crop)
-Livestock
* **Low input**

… And a *F.albida* parkland



*Leguminous nitrogen-fixing specie
* 'reverse phenology'
*'**fertility hotspot**' at tree level
*And various other tree species

Where, What, How? Materials & Methods

At the nexus of remote sensing, landscape ecology and statistical modelling

DATA | METHODS AND OUTPUTS

AGRONOMICAL SURVEY
[MILLET – 50 FIELDS]
[4 CLASSES OF LANDSCAPE]
[2 CROPPING SEASONS]

1.Agricultural practices	2.Tree inventory	3.Yield components

Where, What, How? Materials & Methods

At the nexus of remote sensing, landscape ecology and statistical modelling

DATA	METHODS AND OUTPUTS

AGRONOMICAL SURVEY
[MILLET – 50 FIELDS]
[4 CLASSES OF LANDSCAPE]
[2 CROPPING SEASONS]

1.Agricultural practices	2.Tree inventory	3.Yield components

Linear Mixed model → 1-TREE EFFECT

Where, What, How? Materials & Methods

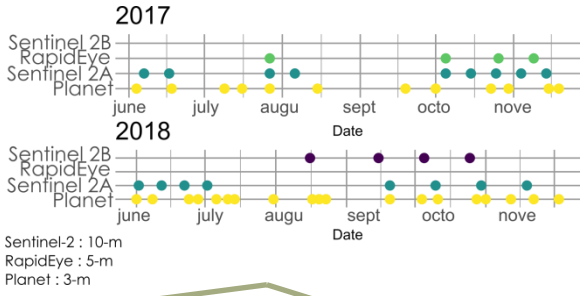
At the nexus of remote sensing, landscape ecology and statistical modelling

DATA

AGRONOMICAL SURVEY
[MILLET – 50 FIELDS]
[4 CLASSES OF LANDSCAPE]
[2 CROPPING SEASONS]

- **1.Agricultural practices**
- **2.Tree inventory**
- **3.Yield components**

MULTI-SOURCES REMOTE SENSING



- **1.Parkland structuring proxies**
  - *Nbs of trees
  - *Woody cover
  - *Tree density
- **2.Vegetation productivity proxies**
  - *Phenological metrics
  - *Vegetation indices
  - *Water stress index
  - *Nutrient stress index

METHODS AND OUTPUTS

Linear Mixed model → 1-TREE EFFECT

Where, What, How? Materials & Methods

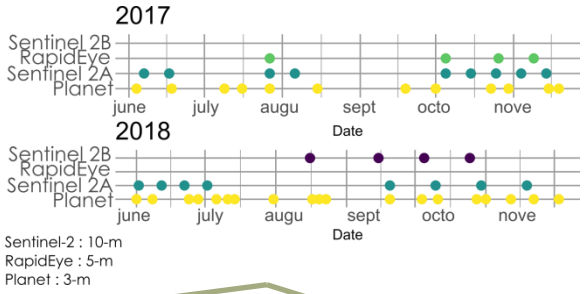
At the nexus of remote sensing, landscape ecology and statistical modelling

DATA

AGRONOMICAL SURVEY
[MILLET – 50 FIELDS]
[4 CLASSES OF LANDSCAPE]
[2 CROPPING SEASONS]

1.Agricultural practices	2.Tree inventory	3.Yield components

MULTI-SOURCES REMOTE SENSING



1.Parkland structuring proxies	2.Vegetation productivity proxies
*Nbs of trees *Woody cover *Tree density	*Phenological metrics *Vegetation indices *Water stress index *Nutrient stress index

METHODS AND OUTPUTS

Linear Mixed model → 1-TREE EFFECT

Linear Regression model → 2-MILLET YIELD ESTIMATES

WITH TREE ↑

WITHOUT TREE ↓

*Plot level

Where, What, How? Materials & Methods

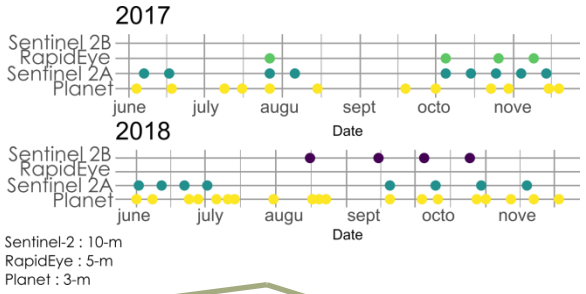
At the nexus of remote sensing, landscape ecology and statistical modelling

DATA

AGRONOMICAL SURVEY
[MILLET – 50 FIELDS]
[4 CLASSES OF LANDSCAPE]
[2 CROPPING SEASONS]

1. **Agricultural practices**
2. **Tree inventory**
3. **Yield components**

MULTI-SOURCES REMOTE SENSING



1. **Parkland structuring proxies**
   - *Nbs of trees
   - *Woody cover
   - *Tree density
2. **Vegetation productivity proxies**
   - *Phenological metrics
   - *Vegetation indices
   - *Water stress index
   - *Nutrient stress index

METHODS AND OUTPUTS

Linear Mixed model → 1-TREE EFFECT

Linear Regression model → 2-MILLET YIELD ESTIMATES
- WITH TREE
- WITHOUT TREE

*Plot level

Gradient Boosting Regression tree model → 3-ANALYSIS OF YIELDS HETEROGENEITY

3.Soil information
- *Texture
- *Soil Org Carbon/Soil Org Nitrogen

Results ~ from a ground perspective

Trees effect at landscape scale based on ground observations

Type II Anova with Kenward-Roger ddf approximation for small sample

Variable	Type II F	P-value
Tree density	47.50	<0.001
F.Albida density	3.01	0.09
F.Albida proportion	12.36	<0.001
Tree species richness	31.78	<0.001
$kgN.ha^{-1}$	12.69	<0.001
Landscape classe	28.47	<0.001

***Significant effects of parkland on millet yields**

Results ~ from a ground perspective

Trees effect at landscape scale based on ground observations

Type II Anova with Kenward-Roger ddf approximation for small sample

Variable	Type II F	P-value
Tree density	47.50	<0.001
F.Albida density	3.01	0.09
F.Albida proportion	12.36	<0.001
Tree species richness	31.78	<0.001
kgN.ha^{-1}	12.69	<0.001
Landscape classe	28.47	<0.001

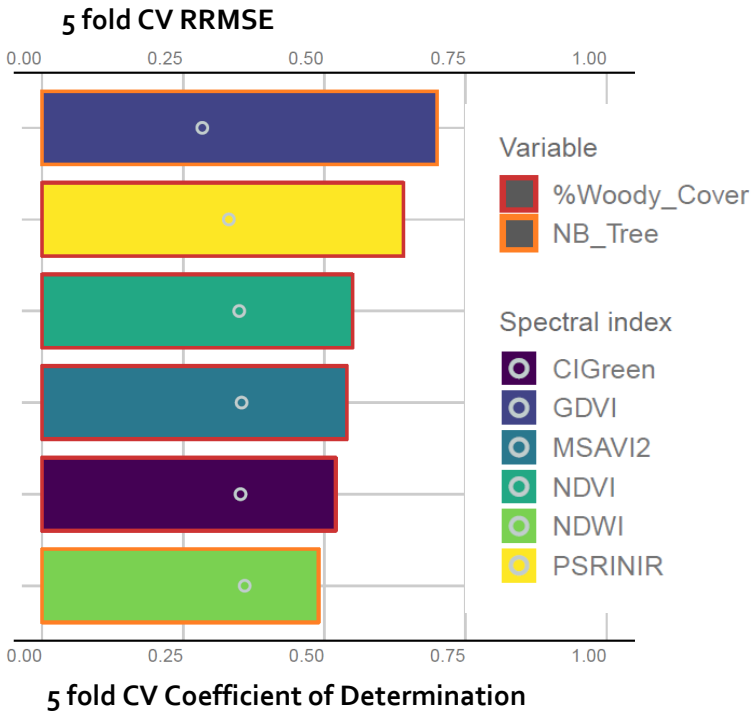
Landscape class	Tree species richness	F.albida proportion	Millet grain yield
Class.1	2.5	18	629
Class.4	4	4	**911**
Class.2	5.6	21	**827**
Class.3	1.7	60	**1334**
pvalue	0.02	0.11	0.09

***Significant effects of parkland on millet yields**
***The well-known 'fertility hotspot' of *F.albiba* can be mitigated at landscape scale by the tree species richness and proportion of *F.albida* within fields**

Results ~ from a plot perspective

From satellite information to yield estimates accounting for tree effects

1~Sensitivity to vegetation productivity proxy and tree information



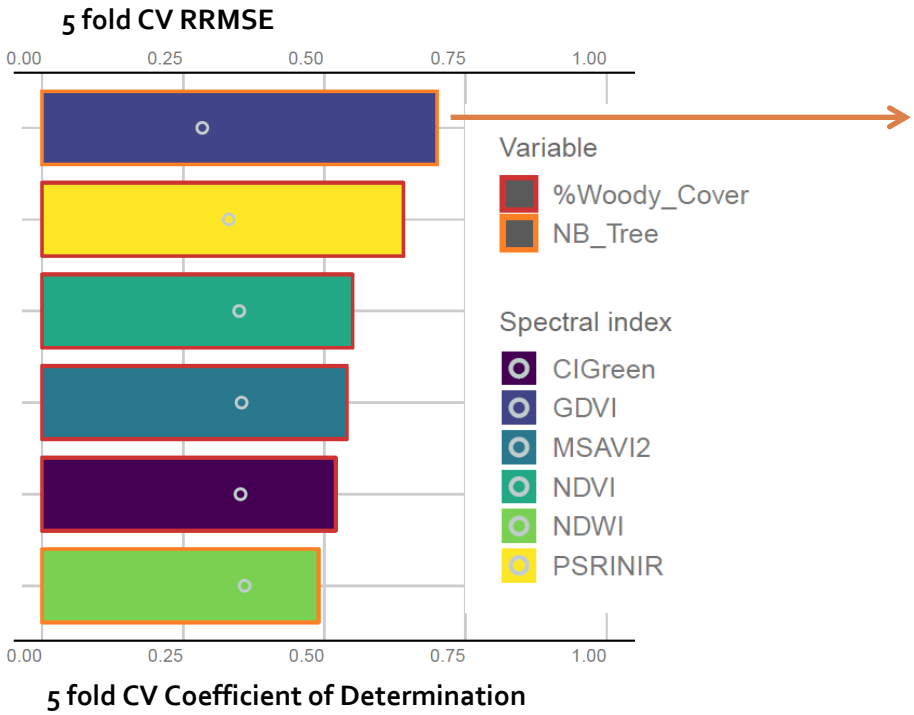
*Integrating parklands structuring information improves millet yield model

*Best model : GDVI x Nb of trees (R^2 0.70 & RRMSE = 0.28)

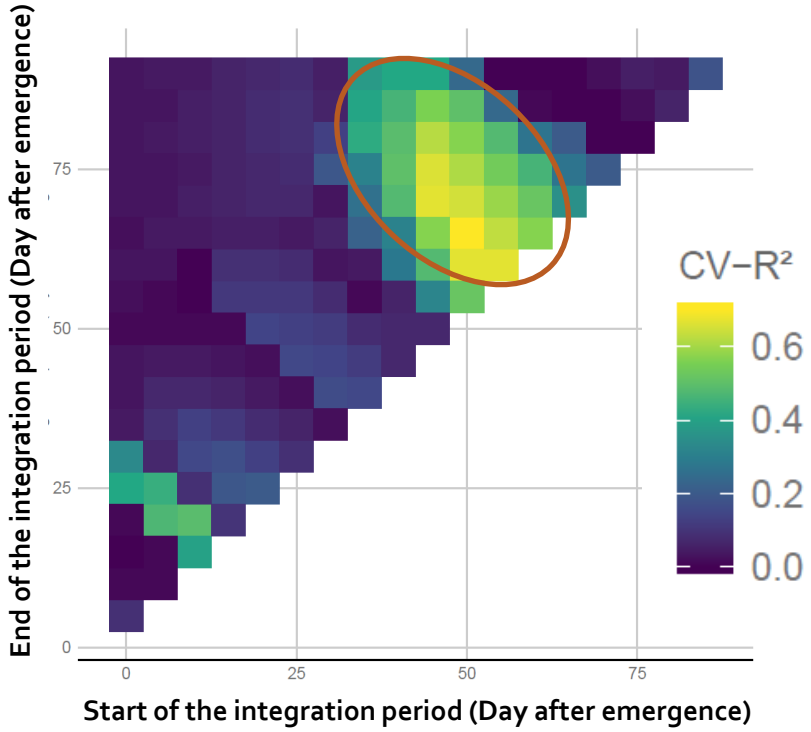
Results ~ from a plot perspective

From satellite information to yield estimates accounting for tree effects

1~Sensitivity to vegetation productivity proxy and tree information



2~Sensitivity to phenological development for GDVI



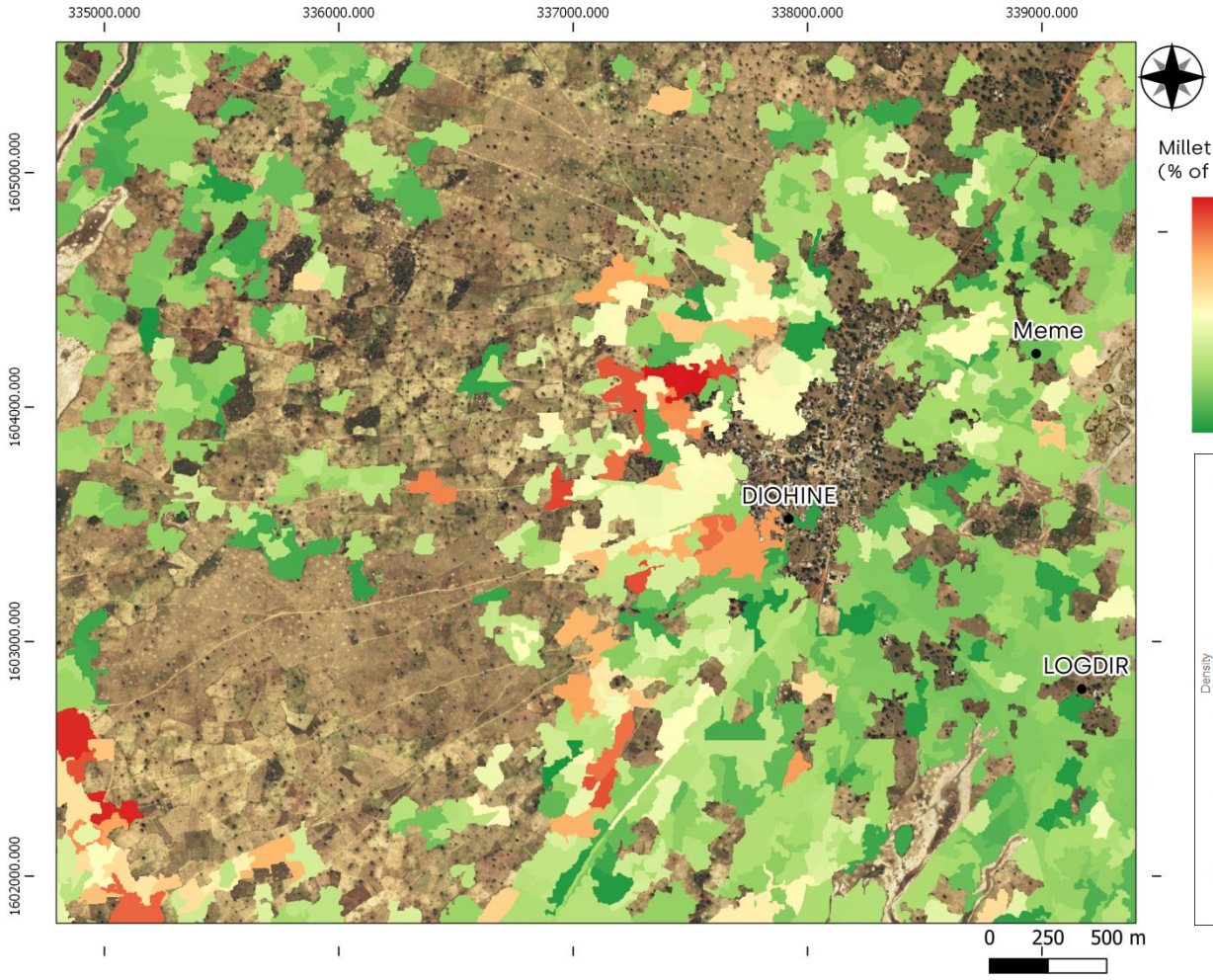
*Integrating parklands structuring information improves millet yield model

*Best model : GDVI x Nb of trees (R^2 0.70 & RRMSE = 0.28)

* Panicle initiation phase to mid of the grain filling phase are more sensitive period

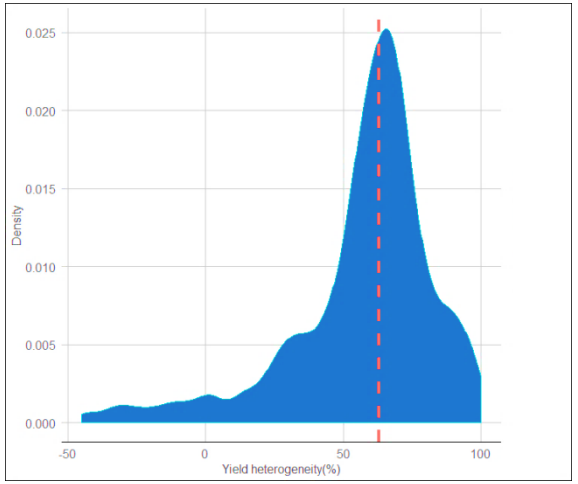
Results ~ from a landscape perspective

Millet yield heterogeneity analysis at landscape scale



HETEROGENITY IN 2018

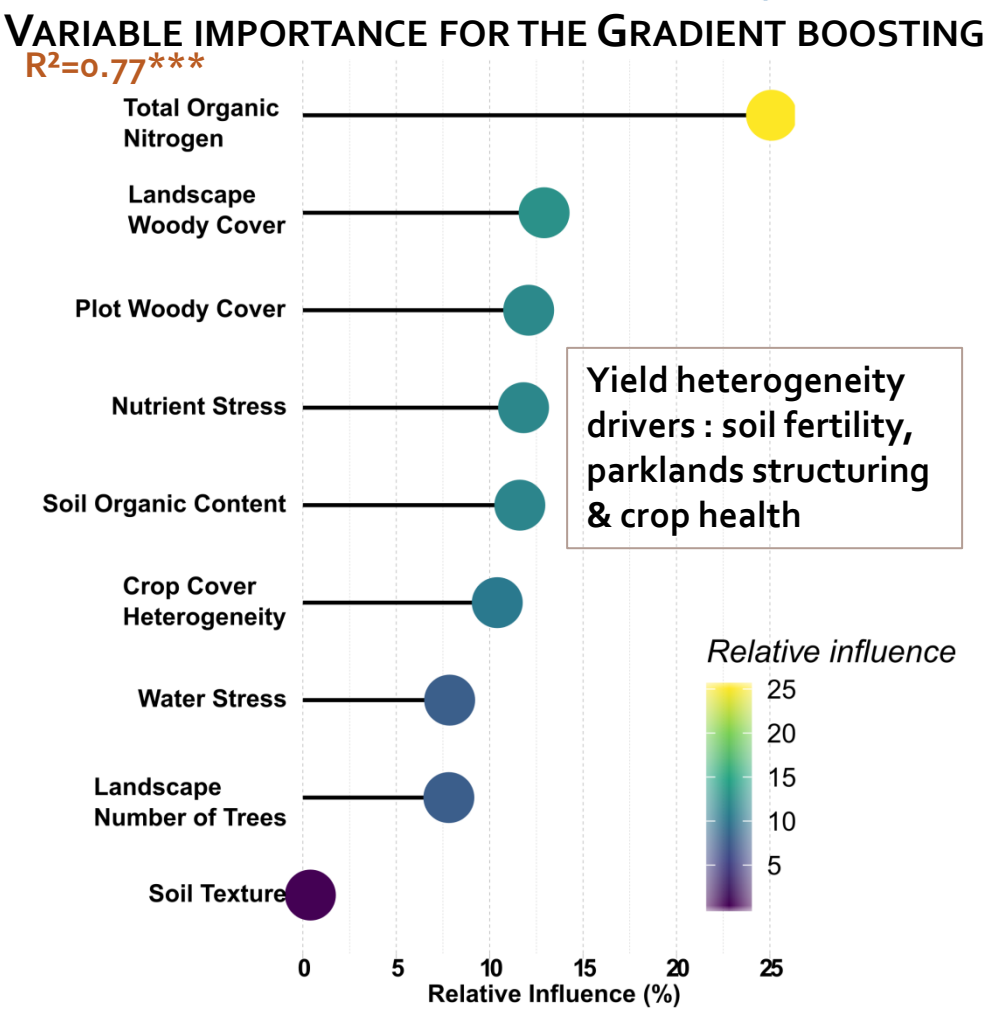
* Comparison with the 95th percentile
* 95th.p > 1912 kg/ha



***Median millet yield estimates = 730 kg/ha with high variability (coef.var = 61%)**
***High spatial heterogeneity, with a clear spatial pattern**

Results ~ from a landscape perspective

What are drivers of spatial heterogeneity pattern?



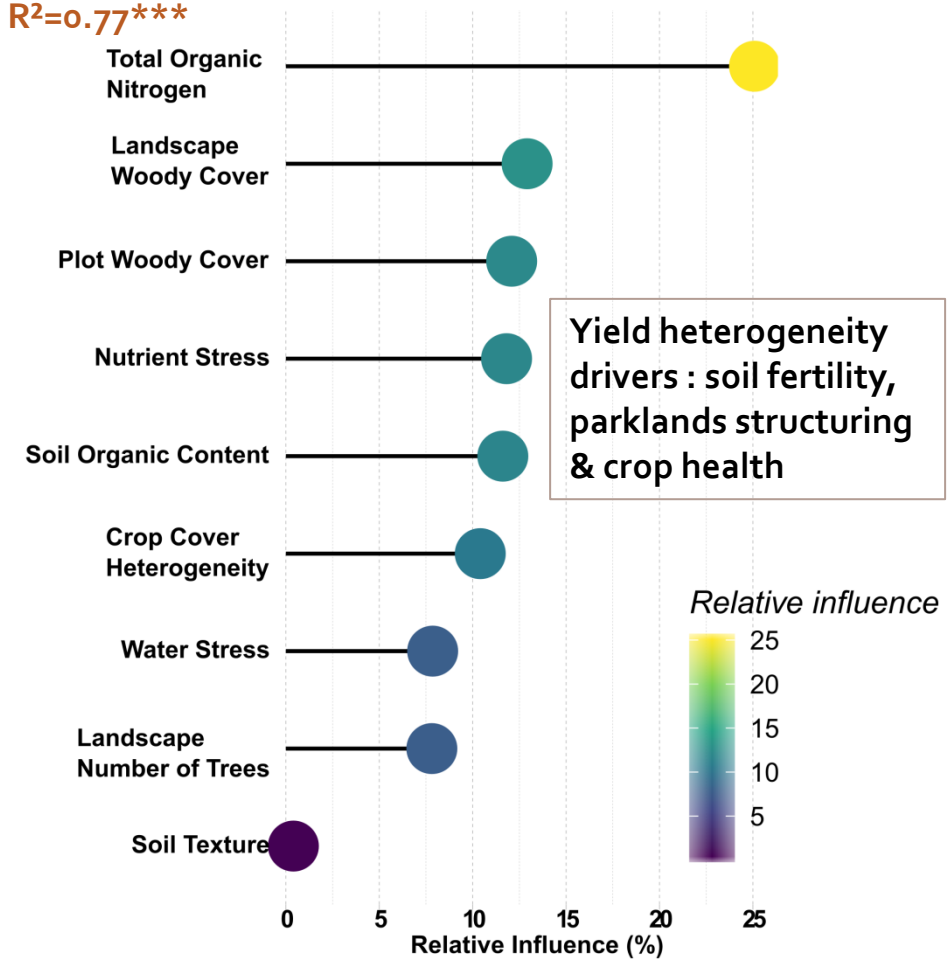
Yield heterogeneity drivers : soil fertility, parklands structuring & crop health

*Parkland structuring information and soil fertility as drivers of spatial heterogeneity

Results ~ from a landscape perspective

What are drivers of spatial heterogeneity pattern?

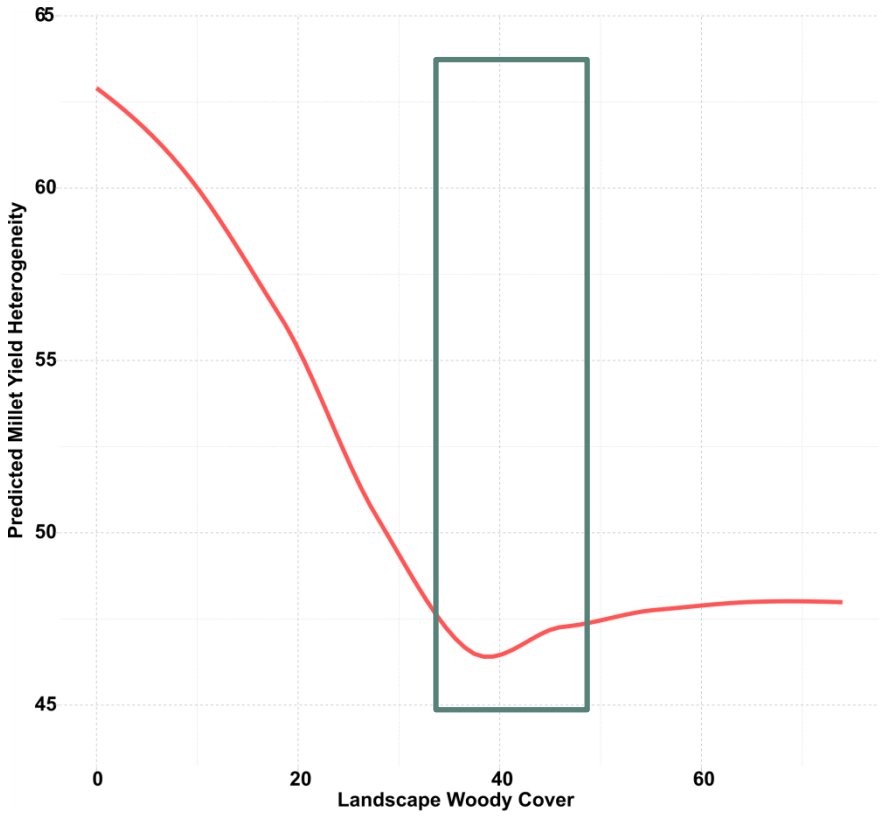
Variable importance for the Gradient boosting tree



Yield heterogeneity drivers : soil fertility, parklands structuring & crop health

Partial Variable Dependance plot

Influence of woody cover in surroundig landscape



*Parkland structuring information and soil fertility as drivers of spatial heterogeneity

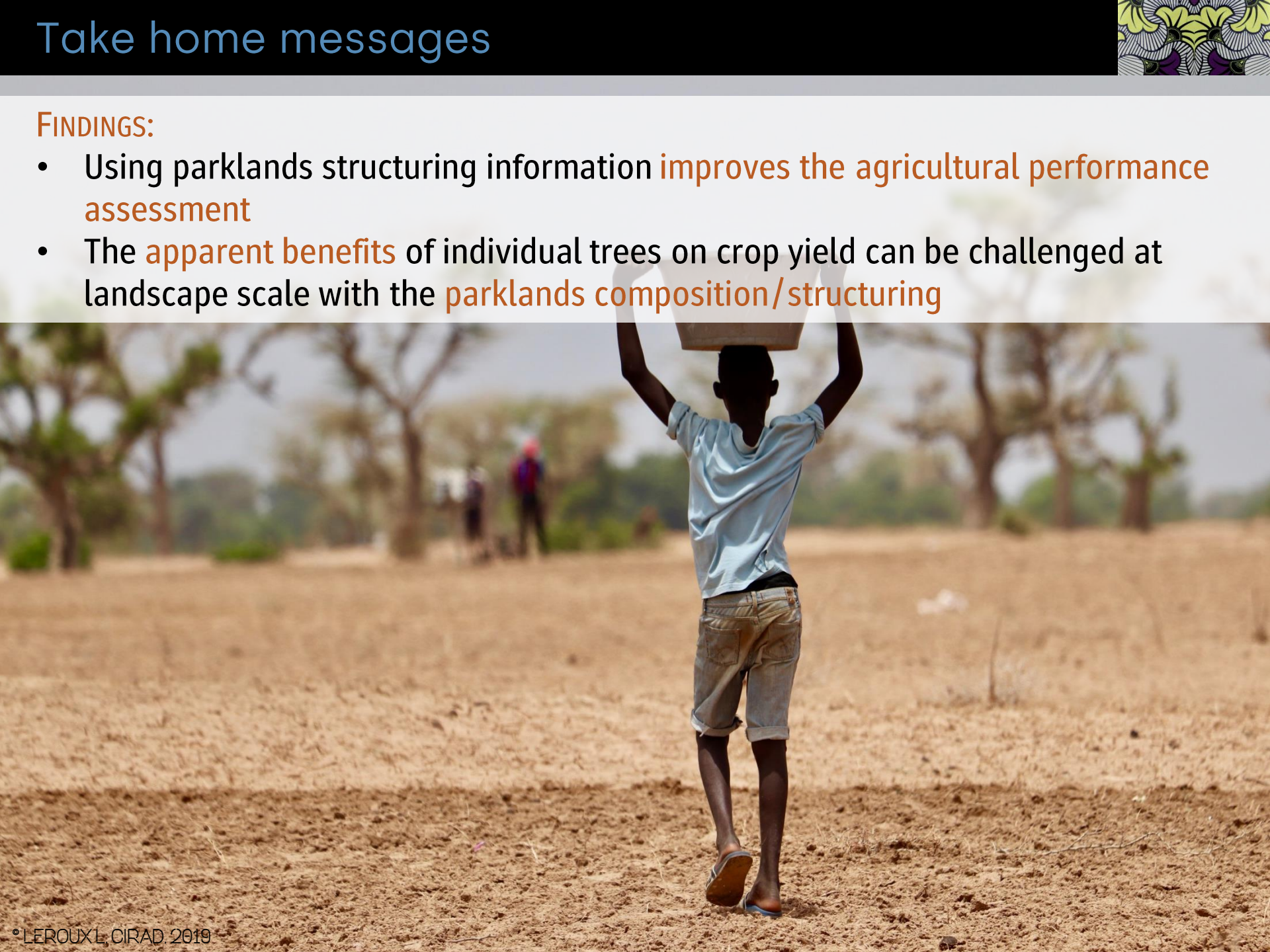
* Woody cover in field surrounding landscape decreases the YH till a certain level

Take home messages

Take home messages

FINDINGS:

- Using parklands structuring information improves the agricultural performance assessment
- The apparent benefits of individual trees on crop yield can be challenged at landscape scale with the parklands composition/structuring



Take home messages

FINDINGS:

- Using parklands structuring information improves the agricultural performance assessment
- The apparent benefits of individual trees on crop yield can be challenged at landscape scale with the parklands composition/structuring

WHAT IS NEW?

- To scaling up crop yields estimates in parklands using cutting edge multisources remote sensing images
- To consider the landscape scale to explore & improve our understanding on the implication of trees on crop productivity

Take home messages

FINDINGS:

- Using parklands structuring information improves the agricultural performance assessment
- The apparent benefits of individual trees on crop yield can be challenged at landscape scale with the parklands composition/structuring

WHAT IS NEW?

- To scaling up crop yields estimates in parklands using cutting edge multisources remote sensing images
- To consider the landscape scale to explore & improve our understanding on the implication of trees on crop productivity

NEXT STEPS?

- To analyze the intra-field variability
- To map tree species to strenghten the analysis of parklands impacts at landscape scale
- To combine with socio-economic information to consider tradeoffs and synergies between goods & services

6th International Symposium for Farming Systems Design

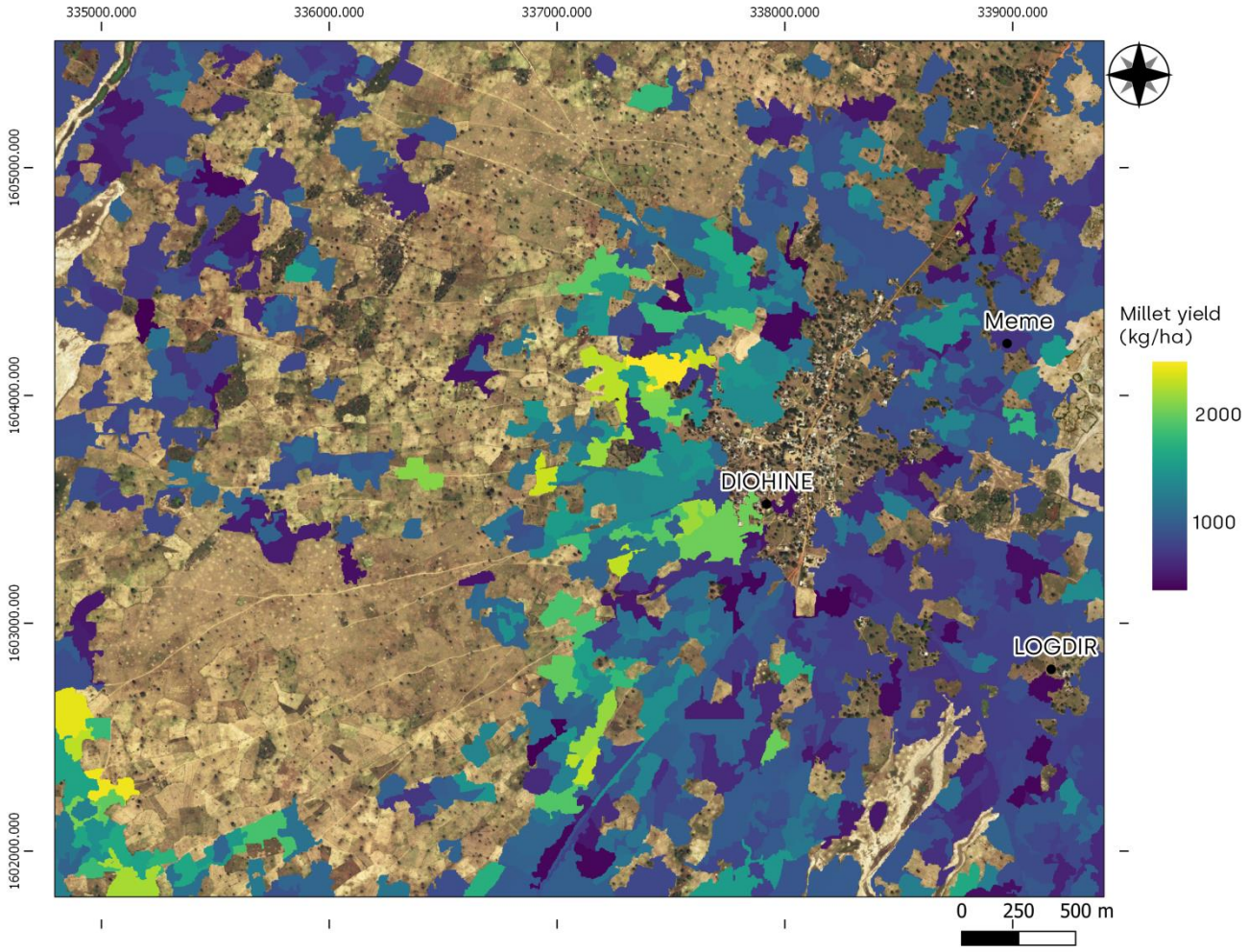
THANKS FOR YOUR ATTENTION

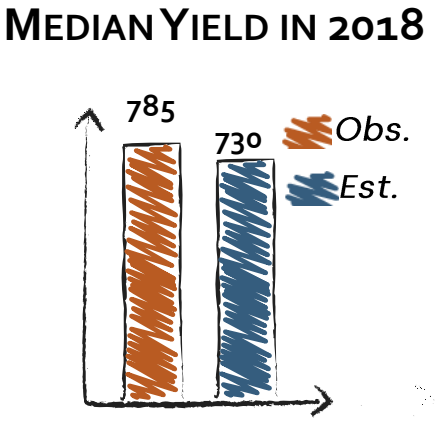
QUESTIONS-REMARKS : louise.leroux@cirad.fr - https://louise.leroux.igeo.fr/

Integrating isolated trees improves the agricultural performance assessment of smallholder farming systems at landscape scale in the Senegalese peanut basin

Results ~ from a landscape perspective

Millet yield heterogeneity analysis at landscape scale





*Median estimated millet yield for 2018 = 730 kg/ha with high variability (coef.var = 61%)